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Energy Saving of Wireless Sensor Network Based on Topology Control Algorithm

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ABSTRACT Wireless sensor networks are an important part of the Internet of Things (IoT). For energy-constrained wireless sensor networks, research on topology control with energy saving is a difficult problem. The influence of topology on the overall performance of the network plays an important role, and the topology control algorithm plays a decisive role in the formation of the topology. Based on the research of hierarchical topology control algorithm, an improved algorithm based on energy-saving clustering algorithm (CAEC) is proposed. The algorithm changes the cluster area and performs communication stability by selecting cluster head nodes. The simulation experiments show that the clustering process of the CAEC algorithm is more reasonable than the LEACH algorithm, which prolongs the survival time of the network. The number of surviving nodes in the monitoring area, network energy consumption, and BS receiving data volume are different degrees of improvement during our study.

INDEX TERMS Energy saving, wireless sensor network, cluster reconstruction, surviving node, topology control algorithm.

I. INTRODUCTION

The combination of science and technology such as semiconductors, microelectronics, artificial intelligence and computers and wireless communication technologies has formed a wireless sensor network. Simply put, the network includes the process of acquiring, processing and transmitting information on monitoring targets in the monitoring area. From the perspective of network architecture, its networking is simple, flexible and has special application [1]. Therefore, the communication bridge can provide users with more timely, more accurate and more realistic monitoring information. From the perspective of network applications, it is no longer limited to the initial military field, but also includes monitoring of the natural environment, building status, and public space security [2]. The network can be used to monitor various parameters such as noise, temperature, pressure, humidity, and strength in the monitoring area. Since the energy of the sensor node is shortly referred to as the node itself, the optimal topology control algorithm is used to efficiently use the node energy to achieve extension. The purpose of network lifetime is an important direction of energy-saving research in wireless sensor networks. Because network nodes have the characteristics of low carrying capacity, low processing speed and small storage space, a low-power, low-cost wireless sensor network is formed [3]–[6]. Wireless sensor networks are at the forefront of new technologies. There are still many hot topics worth exploring. Domestic and foreign scholars are conducting in-depth research. At present, there are few systematic data available for reference in China [7]. Different researchers have different opinions on many problems of wireless sensor networks [8], [9]. For example, in the problem of node naming, some scholars believe that there is no need to assign a unique identifier to each node, and use attribute-based methods to identify a class of nodes [10]. Scholars believe that each node needs to be assigned a unique identifier [11]–[14].

The challenge of sensor networks also provides researchers with a broad research space [15]. Although the United States has started research in this area very early, it has not been until recently that research activities in this area have flourished in universities and research institutes. The US government has also invested heavily in supporting research in this area. One of the topics of the annual Natural Science Foundation's

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autonomous project is the sensor and sensor system and network, with a grant of $34 million [16]. Many universities in the United States have conducted research on sensor networks. In other countries and regions, such as Europe, Japan, and Australia, a lot of research work on sensors and sensor networks has been carried out. The University of California at Berkeley proposes a method for reconstructing sensor locations using network connectivity, a data encoding model based on correlation, a method for reconstructing a track of moving objects using a sparse sensor network, and a continuous stream visualization method over time on a sensor network [17]. Lu et al. have developed a wireless sensor network and a wireless sensor network simulation environment to examine various aspects of the sensor network [18]. They propose a distributed system technology that does not rely on network topology for low-level communication, and supports multi-application sensor networks. The software structure intra-network data processing included hierarchical initial structure for conversion of advanced data streams, time synchronization solution for sensor networks, design problems and solutions for self-organizing sensor networks, new multi-path modes, etc. The TopoDisc algorithm based on the idea of minimum dominance set, although very fast, does not take into account the problem of energy balance, and therefore affects network lifetime [19]. Although the Energy Saving via Opportunistic Routing algorithm proposed by Luo et al. can generate a network with k connectivity, but the algorithm has higher requirements on the sensor [20]. In the case of a large network scale, the corresponding cost will also increase.

Based on the above preliminary understanding of the wireless sensor network topology control algorithm, this paper intends to find a more optimized algorithm, based on the research of hierarchical topology control algorithm, an improvement based on CAEC (energy saving clustering algorithm) is proposed. algorithm. The algorithm changes the cluster area and performs communication stability by selecting a cluster head node. So that the performance of the network is improved to a certain extent to achieve the purpose of extending the network lifetime, that is, the survival node of the network is more, consume less energy, and receive more data. The rest of this paper is organized as follows. Section 2 discusses Wireless sensor network topology control, followed by Wireless sensor network energy-saving design in Section 3. In Section 4, we discuss influence of topology on energy consumption of topology control algorithm. Section 5 shows the experimental results and analysis, and Section 6 concludes the paper with summary and future research directions.

II. WIRELESS SENSOR NETWORK TOPOLOGY CONTROL

Network topology control is of particular importance for wireless, self-organizing wireless sensor networks [21]. The good network topology automatically generated by topology control can improve the efficiency of routing protocols and protocols, and lays a foundation for many aspects such as data fusion, time synchronization and target location, which helps to save node energy and prolong the lifetime of the network [22]. Therefore, topology control is one of the core technologies of wireless sensor network research.

A. WIRELESS SENSOR NETWORK ARCHITECTURE

Wireless sensor networks and autonomous intelligent systems based on wireless sensor networks are comprehensive technologies involving multi-disciplinary systems such as microcomputer electromechanical systems, computers, communications, automatic control, and artificial intelligence [23]. The behavior realization and control of autonomous systems with swarm intelligence is the frontier research content in the field of automatic control and artificial intelligence, which provides powerful technical support for the intelligence of wireless sensor networks [24]. The wireless sensor network is a "smart" autonomous measurement and control network system composed of a large number of ubiquitous, small sensor nodes with communication and computing capabilities densely arranged in an unattended monitoring area to perform specified tasks according to the environment [25].

Wireless sensor networks have many similarities with wireless ad hoc networks. Some documents even use wireless sensor networks as a kind of wireless ad hoc networks [26]. First of all, the application goals of the two are different. Wireless ad hoc networks are the main goal of providing users with high-quality data transmission services without relying on any infrastructure. Wireless sensor networks are primarily aimed at monitoring the physical world. In this sense, a wireless ad hoc network is a data network, and a wireless sensor network is a measurement and control network. Secondly, wireless sensor networks are characterized by large scale, unattended, susceptible to physical environment and strong dynamics. These characteristics determine that wireless sensor networks need to have a different architecture than wireless ad hoc networks.

Wireless sensors, sensing objects and observers are the three basic elements of wireless sensor networks [27]. Wireless is the communication between sensors, sensors and observers. It is used to establish and communicate the communication path between the sensor and the observer [28]. Processing, distributing and transmitting perceptual information is the basic function of wireless sensor networks. A set of limited wireless sensors can cooperate to complete large sensing tasks. It is an important feature of wireless sensor networks. Some or all nodes in wireless sensor networks can move, wireless sensor networks. The topology also dynamically changes as nodes move. Nodes communicate in a way that each node can act as a router, and each node has the ability to dynamically search, locate, and restore connections [29].

Below, we discuss sensors, perceptions, and observers in detail. The sensor node is composed of a sensor module, a processor module, a wireless communication module and an energy supply module, as shown in Figure 1.

The sensor module is responsible for monitoring the collection of information in the area and the switching of the

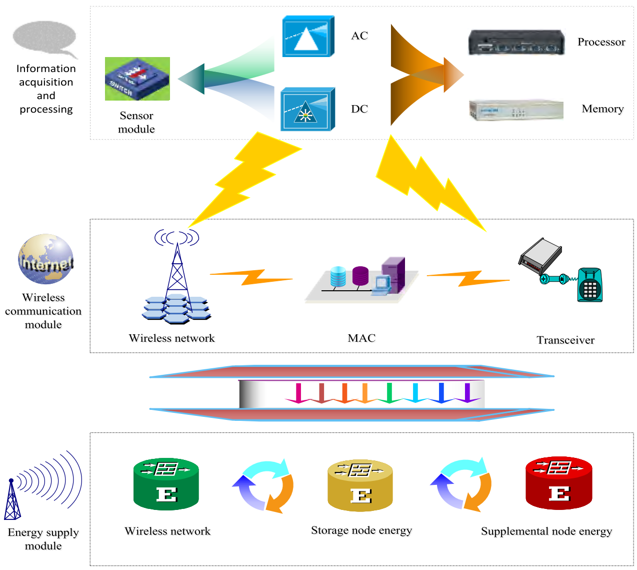

FIGURE 1. **Architecture of a wireless sensor node.**

data. The processor module is responsible for controlling the operation of the entire sensor node, storing and processing the data collected by itself and the data sent by other nodes. The wireless communication module is responsible for wirelessly communicating with other sensor nodes. Switching Control Messages and Transceiver Acquisition Data The energy supply module provides the sensor nodes with the energy they need to operate, typically using a miniature battery. A wireless sensor network may have multiple observers, and one observer may also be a user of multiple wireless sensor networks. The observer can actively query or collect the sensing information of the wireless sensor network or passively receive the information published by the wireless sensor network. The observer will observe, analyze, mine, make decisions or take appropriate action on the perceived object.

In terms of architecture, the wireless sensor network is composed of a sensor node, a sink node, a play or communication satellite, and a task management node [30]. Sensor nodes are scattered in a specified sensing area, and each node can collect data and transmit data to the node through ''multi-hop'' routing. Nodes can also send information to nodes in the same way. In a typical wireless sensor network, nodes are randomly scattered in the monitored area, which is done by means of aircraft broadcast, artificial embedding and rocket ejection. Of course, some wireless sensor networks are placed by manual placement [31]. The nodes form a network in a self-organizing manner, and the monitoring data is transmitted to the node through multi-hop routing, and finally the data in the entire area is transmitted to the remote center by means of a long-distance or temporarily established link. The architecture of the wireless sensor network node is shown in Figure 2.

B. WIRELESS SENSOR NETWORK TOPOLOGY CONTROL

In the sensor network, the sensor node is a small embedded device, powered by a battery with limited energy, and its

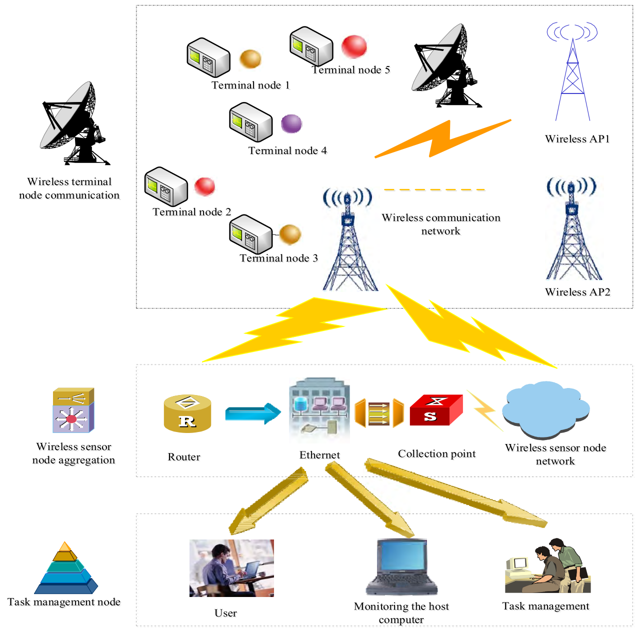

FIGURE 2. **Wireless sensor network node architecture.**

computing power and communication capability are very limited, so in addition to designing energy efficient MAC protocols, routing protocols, and application layer protocols. Also design an optimized network topology control mechanism. Topology control generally refers to the network administrator's use of dedicated network management software to automatically generate the topology of the network. Different from the traditional network, the wireless sensor network is a self-organizing network. The number of nodes in a wireless sensor network is several orders of magnitude higher than the number of Ad hoc network nodes. The biggest feature of a self-organizing sensor network is energy limitation. Sensor nodes are limited by the environment and are usually powered by batteries that have limited power and are not replaceable. Therefore, energy saving is one of the main design goals when considering sensor network architecture and layer protocol design. Due to the particularity of the environment of wireless sensor network application, the instability of wireless channel and the limitation of energy, the probability of sensor network node damage is much greater than that of traditional network nodes. Therefore, the robustness of self-organizing network is necessary to ensure part. Damage to the sensor network does not affect the global task. High-density deployment of wireless sensor nodes and rapid changes in network topology pose serious challenges to the design of topology maintenance routing protocols.

The main research problem of sensor network topology control is that under the premise of satisfying network coverage and connectivity, through power control and backbone network node selection, unnecessary communication links between nodes are eliminated, and an optimized network structure for data forwarding is formed. In particular, the topology control in the sensor network can be divided into two types of node power control and hierarchical topology organization according to the research direction. The power control mechanism adjusts the transmit power of each node in the network. Under the premise of satisfying the network connectivity, the single-hop of the balanced node can reach the number of neighbors.

In general, clusters are the basic unit of wireless sensor network topology, and the topology of wireless sensor networks is usually composed of multiple clusters. Similar to the way crystals are generated, sensor networks can be in two clusters. One is called the ''single crystal'' method, and the other is called the ''polycrystalline'' method. In the single crystal structure, the clusters in the network are initiated by a unique root node. Each cluster node that requests to join must send a request to the root node. According to the different responses of the root node, the node that issued the application can join the existing node. Cluster or form a new cluster. In the ''polycrystalline'' mode, all nodes spontaneously discover other nodes and form independent clusters according to certain rules. The clusters can establish connections.

III. WIRELESS SENSOR NETWORK ENERGY-SAVING DESIGN

A. NODE ENERGY EFFICIENCY MODEL

In the monitoring area, the node has three features. First, several nodes cooperate with each other to form an effective communication path, realize data communication from the source node to the target node, and complete monitoring of the monitoring target. Second, when the processing capability is limited, the node processes the data of the monitoring target through the collector, mainly by eliminating the redundant information by data fusion, and then handing the merged data to the communication module of the node. Third, the node has the capability of wireless communication, that is, the transmission and reception of data can be completed.

When a node sends or receives information, it consumes more energy than when performing calculations. For example, the energy consumed by transmitting 1 bit of information separated by 100 m can execute 3000 calculation instructions, so the node usually needs to locally process the original data to reduce network transmission. The amount of data. It reflects the process of local processing of raw data. First, the pre-processing of the data packet is determined by the network application of the monitoring area, which may include data fusion, de-encryption or sub-category. Then, the data processing extracts valuable information, and if the information needs to be forwarded to the neighbor node, the information is compressed or encrypted and delivered to the transmitting device. A schematic diagram of the BS and the monitoring area is shown in Figure 3.

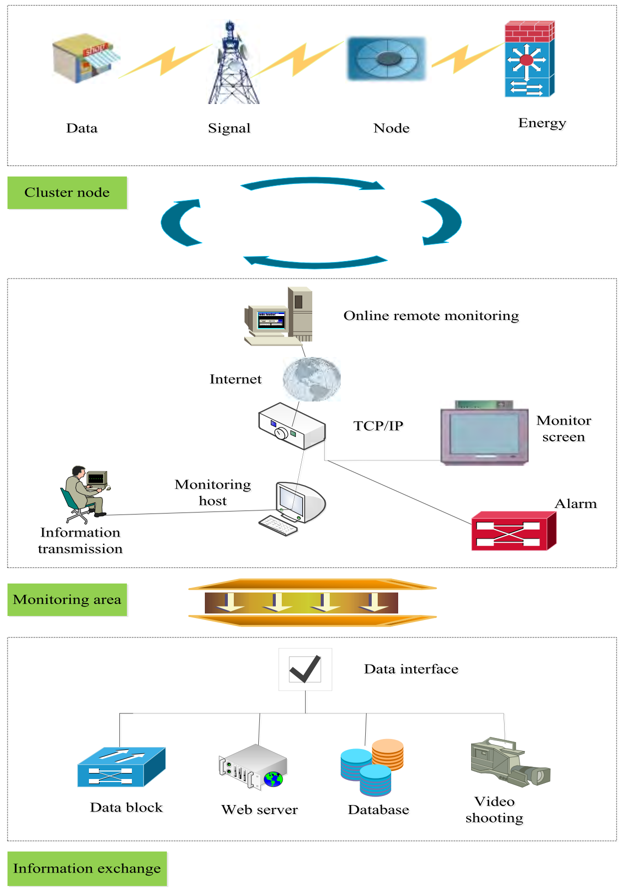

FIGURE 3. Schematic diagram of BS and monitoring area.

B. ANALYSIS OF COMMUNICATION ENERGY CONSUMPTION

Assume a simple wireless communication model, which is mainly composed of a transmitting circuit, an amplifying circuit, and a receiving circuit. Its energy consumption is:

$$E_{Tx}(k,d) = E_{Tx-elec}(k) + \varepsilon(k,d) = \begin{cases} k \times E_{elec} + k \times \varepsilon_{fs} \times d^2 & d < d_0 \\ k \times E_{elec} + k \times \varepsilon_{amp} \times d^4 & d \geq d_0 \end{cases} \quad (1)$$

where d_0 represents the critical distance. Accordingly, the energy consumption to accept this information is

$$E_{Rx}(k,d) = E_{Rx-elec}(k) = k \times E_{elec} \quad (2)$$

The relationship between the energy consumption of wireless communication and the communication distance is

$$E = \eta d^n \quad (3)$$

where η represents the coefficient of energy consumption, and n represents the communication path loss index, satisfying the relationship $2 < n < 4$. Taking the critical distance d_0 as the limit, the wireless communication model can be divided into two categories. When $d < d_0$, it is a free-space channel model. At this time, n is 2, the amplifier coefficient is ε_{fs}, when $d \geq d_0$ is the multipath fading channel model, then n takes 4. The amplifier coefficient is ε_{amp}. In these two types of models, the parameters of wireless communication are shown in Table 1.

TABLE 1. Parameters of wireless communication.

Operating		Average energy consumption
Transmitting circuit		55nJ/bit
Receiving circuit		
Amplifier coefficient	ε_{fs}	11pJ/bit/m^2
	ε_{amp}	0.0012pJ/bit/m^4

TABLE 2. Internal routing communication characteristics.

Number of neighbors	Tx	Rx	Energy used/J
4	10	29	10.873×10^4
5	9	35	13.049×10^4
6	8	34	11.203×10^4
7	6	28	9.078×10^4
8	6	32	10.239×10^4
9	6	37	11.632×10^4

TABLE 3. Boundary routing communication characteristics.

Number of neighbors	Tx	Rx	Energy used/J
4	15	34	14.073×10^4
5	10	29	11.049×10^4
6	12	39	13.203×10^4
7	12	41	14.078×10^4
8	12	42	14.239×10^4
9	12	47	15.632×10^4

C. ROUTE ENERGY EFFICIENCY ANALYSIS

The following analysis of routing energy efficiency, respectively discussed the energy consumption of the boundary and internal routing methods. Assume that the degree of freedom refers to the number of communication paths available for routing protocol selection.

1) INTERNAL ROUTING

Internal routing refers to the number of neighbor nodes of a node being stable and belonging to the same network center. The internal routing communication feature shown in Table 2 indicates the amount of transmitted data, indicating the amount of received data. When the amount of transmitted data is constant, the amount of received data increases as the number of neighboring nodes increases. This is because when the number of neighbor nodes increases, there is a higher degree of freedom from the source node to the target node, and the communication task needs to go through multiple paths.

2) BORDER ROUTING

As shown in Table 3, when the number of neighbor nodes increases, the number of neighbor nodes that receive the data packet also increases, which in turn increases the energy consumed by the network.

As can be seen from the above two tables, in the case where the neighbor nodes are the same, and the amount of transmitted and received data is similar, the boundary route consumes more energy than the internal route. This is because the number of neighbor nodes is more than the internal route when transmitting along the boundary, and the number of neighbor nodes increases, and the amount of transmitted data increases accordingly, eventually resulting in an increase in the energy consumed.

D. ENERGY-SAVING DESIGN ANALYSIS

For the node energy efficiency model, the message header file is used to store the basic characteristics of the message. When the source node sends a message, it adds a message header file to the front end of the message, and the target node analyzes the characteristics and processing requirements of the message according to the message header file after receiving the message.

For communication energy analysis, the shortest communication path can be reduced to reduce the total number of hops to reduce the total energy consumption. Alternatively, the total number of neighbors can be minimized by selecting the path with the minimum number of neighbors.

For route energy efficiency analysis, balance between boundary route and internal route is required when performing route calculation, that is, try to ensure that the number of neighbor nodes of each node is equal.

For the topology design, when the number of neighbor nodes increases, the message received by the node increases correspondingly, and the message sent at the same time is correspondingly reduced. Therefore, an energy-efficient topology needs to balance the relationship between sending and receiving messages in a quantitative manner.

IV. INFLUENCE OF TOPOLOGY ON ENERGY CONSUMPTION OF TOPOLOGY CONTROL ALGORITHM

The energy consumption of a topology control algorithm runs from two aspects, one is the energy consumed when the network topology is initialized. In this process, the network's links are transformed from a natural distribution to an artificially designed topology. Undoubtedly, all nodes must participate in this process, and it is obvious that for a network with a densely distributed and widely distributed network, it takes longer to generate a topology. Therefore, in the early stage of the research of topology control algorithms, people pay more attention to the energy consumption of the algorithm itself in the initialization stage of the topology. However, as the research progresses, more and more researchers find that this evaluation method is not appropriate. First, the characteristics of the wireless sensor network determine that the node has a long running time and the link quality is unstable, and the nodes of the backbone network may fail at any time. Therefore, the reconstruction of the topology occurs frequently in the network lifetime.

A. SIMPLE GLOBAL STRUCTURE ALGORITHM

Simple global structure algorithms include flooding trees and distributed flooding trees. Flooding tree algorithm has

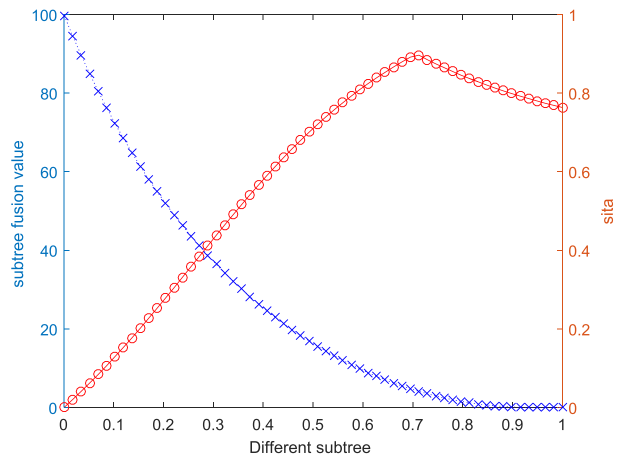

FIGURE 4. Different subtree fusion process.

been standardized. The main idea is to iteratively join nodes and edges from the root node until all nodes are covered. This algorithm is usually represented by a color, a black node indicates a node that has joined the tree, and a white node indicates a node that has not joined the tree. The algorithm flow is roughly as follows:

First we need to initialize all node colors to white. We select a node as the root node of the tree and set its color to black node neighbor broadcast flooding message. The white node receiving the message sets the color to black, remembers the node that sent the message as the parent node, and then repeats this step. The black node does not process any messages. It is easy to prove that this algorithm gets a tree structure. But the way to join the node tree starts at a point on the network. If a critical unreliable link occurs when the tree is small, causing flooding messages to not be sent to other parts of the network, the algorithm will terminate. Therefore, the reliability of this algorithm is not good.

Later, many distributed algorithms appeared, and the VPT proposed by Hichem et al. is one of them. Unlike most flooding tree algorithms, the algorithm does not start with a preset root node, but uses random parameters to generate multiple subtrees in the network. These subtrees are marked with unique colors, and Converged into a single tree through interactive messages. The algorithm also proposes a distributed mechanism for the maintenance of the tree structure. The specific content of the algorithm is as follows

Assume that the identity of each node in the network, that is, the identification number, is different. Each node has a color identifier corresponding to the identification number. Each node generates a random number that identifies the duration of the sleep state. Each node is initially in a sleep state, and a timer is set up. Before the timer expires, the node does not send any message, waiting to receive the invitation message to become a leaf node of the subtree. All node times have been synchronized. After the node wakes up the node for a certain period of time, the timer expires and the node enters the active state. The algorithm subtree generation process is shown in Figure 4.

This topology construction method is relatively new, but there is no doubt that the number of synchronizations and the amount of computation are very large. Because there is no loop between the two subtrees, broadcast flooding needs to be performed inside the respective subtrees.

B. GLOBAL LOCAL STRUCTURE ALGORITHM

The hypothetical nodes of this type of algorithm have the same emission radius and are modeled in unit circles. The original intention is to extend the network life cycle by layering the network. Therefore, the algorithm based on cluster partitioning is the first to propose. The LEACH algorithm solves the problem of network layering well. Its cluster head rotation election mechanism not only ensures that no one node will serve as a cluster head for too long, causing energy to run out, nodes fail, and new cluster head nodes generate information that does not require extensive interaction. This solves the problem of topology maintenance to some extent. Its improved algorithm further reduces the number of cluster head nodes through multi-level layering, and performs better in terms of energy saving. However, the shortcoming of such an algorithm is that its global structure is star-shaped, that is, all cluster head nodes communicate with the sink node in a single hop. This energy-consuming communication method limits the scale of the network, and is also a large-scale sensor of such algorithms. The application value is lost in the network, and the reason for the backbone network algorithm based on the control set is gradually given.

LEACH continuously performs the cluster reconstruction process during the running process. Each cluster reconstruction process can be described by the concept of round. Each round can be divided into two phases: the establishment phase of the cluster and the stabilization phase of the transmitted data. In order to save resource overhead, the duration of the stabilization phase is greater than the duration of the establishment phase. The cluster establishment process can be divided into four phases: the selection of cluster head nodes, the broadcast of cluster head nodes, the establishment of cluster head nodes, and the generation of scheduling mechanisms. The choice of cluster head nodes is determined by the total number of cluster head nodes required in the network and the number of times each node has become a cluster head node so far. The specific choice is that each sensor node randomly selects a value between 0-1. If the selected value is less than a certain threshold, then this node becomes the cluster head node. After the cluster head node is selected, the entire network is notified by broadcast. The other nodes in the network determine the dependent cluster according to the signal strength of the received information, and notify the corresponding cluster head node to complete the establishment of the cluster. Finally, the cluster head node uses the TDMA method to allocate each node in the cluster to the point in time at which data is passed to it. In the stabilization phase, the sensor node transmits the acquired data to the cluster head node. The cluster head node fuses the data collected by all the nodes in the cluster and then

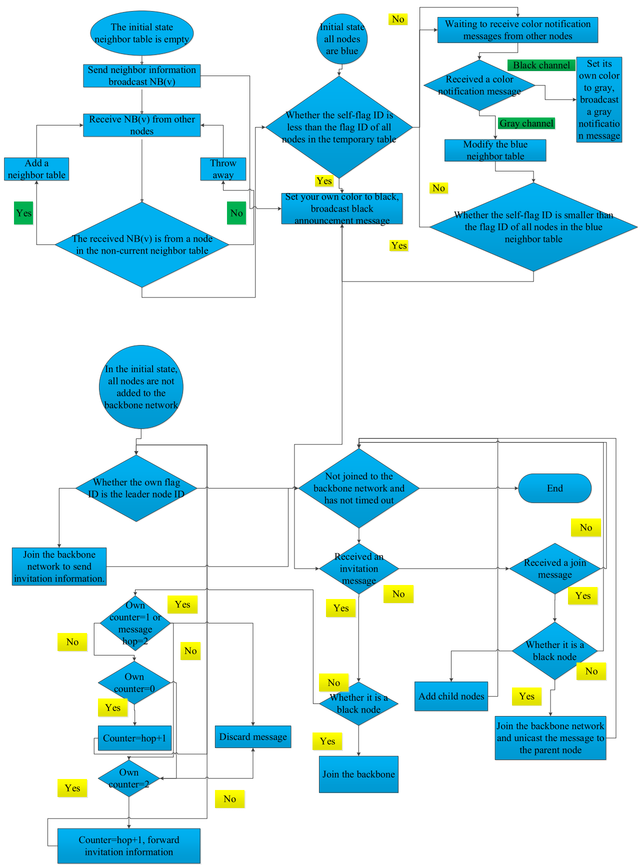

FIGURE 5. Establishment of the MIS-Tree algorithm backbone network.

transmits the data to the sink node. This is a reasonable working model for less communication traffic. After the stabilization phase continues for a period of time, the network re-enters the cluster establishment phase, performs the next round of cluster reconstruction, and continuously cycles. Each cluster uses different CDMA codes to communicate to reduce the interference of nodes in other clusters.

The mechanism of the MIS-Tree algorithm is divided into three stages: collecting neighbor information, establishing a control set, and establishing a backbone network. The flow chart is given below, as shown in Figures 5.

The algorithm will eventually generate a tree-like connected control set as the backbone network. The control set generated by the algorithm is complete under the premise that all messages are correctly received. Because if there are some nodes that are not in the control set and not controlled, then these uncontrolled nodes must not be adjacent to any control nodes.

C. ENERGY CONSUMPTION MODEL

The power p_t of the data transmitted by the wireless communication module, that is, the energy required to transmit rbit data (r is the rate at which data is transmitted) through the link of the Euclidean distance d per unit time can be expressed by the following equation.

$$p_t(r,d) = r(\alpha_1 + \alpha_2 d^n) \tag{4}$$

TABLE 4. Maintenance methods of topology control algorithms of different structure types.

Structure type	Node type	Maintenance method
Global local structure	Ordinary node	No maintenance required
	Gateway node	Partial maintenance or global maintenance
	Control set node	Recalculate the topology across the network and reselect all control set nodes
Simple global structure	Any node	Recalculate topology across the network

The parameter α_1 indicates the thermal power consumed by the transmitting circuit, which is independent of the communication link status; the parameter α_2 indicates the influence of the communication link status on the data transmission, and is usually $2 \leq \alpha_2 \leq 4$. If it is lower than this value, the data will be discarded as noise by the communication module of the receiving node because the signal-to-noise ratio is too low.

The power p_r at which the wireless communication module receives data at the rate r can be expressed by the following equation.

$$p_r(r) = r\beta \tag{5}$$

wherein the parameter β represents the power of the receiving circuit. Obviously, the lower power limit of the node forwarding data can be expressed as

$$p_f(r,d) = r\left[(\alpha_1 + \beta) + \alpha_2 d^n\right] \tag{6}$$

Therefore, the total power of the node communication module is

$$p(t) = p_t[r(t),d] + p_r[r(t)] + p_f\,[r(t),d] \tag{7}$$

Assume that the number of network nodes is n, the initial time is t_0, and the lifetime is l. Then the power consumption of node i at time t' is

$$E_i(t') = \int_{t=t_0}^{t=t'} p(t)dt \tag{8}$$

The total energy consumption of the network is

$$E_N(t') = \sum_{i=1}^{n} E_i(t') \tag{9}$$

D. SIMULATION ANALYSIS OF ENERGY CONSUMPTION OF DIFFERENT TYPES OF TOPOLOGY CONTROL ALGORITHMS

We have classified the sensor network topology control algorithm according to the topology generated by it, and introduced and analyzed the typical algorithms of each type. Now we can summarize the maintenance methods as shown in Table 4:

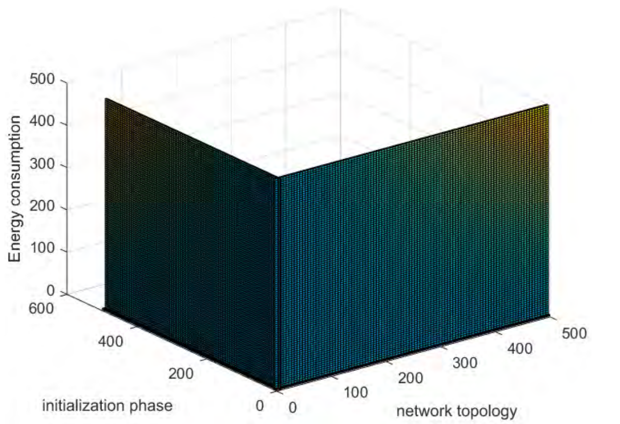

FIGURE 6. Energy consumption of the algorithm during the initialization phase of the network topology.

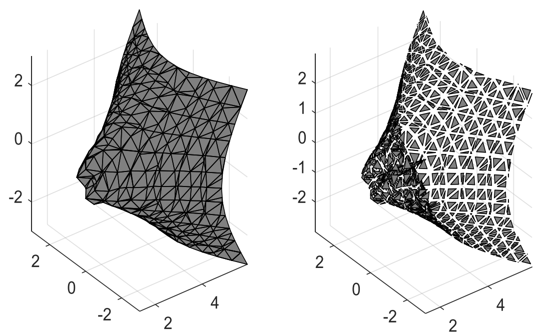

FIGURE 7. Energy consumption of the algorithm during the maintenance phase of the network topology.

We choose flooding tree algorithm and MIS-Tree algorithm as the object of simulation analysis. The former is a representative of a purely global algorithm, and its mechanism is extremely simple, which we consider representative. The latter is a representation of the global local type (the global structure is a tree, and the cluster structure exists locally). The simulation results are shown in Figure 6.

In Figure 6, we can see that in the topology initialization phase, with the color and curve of the curve and topology curve, the energy consumption of the MIS-Tree algorithm is significantly increased, and with the increase of the network scale, the energy consumption and the trend of the MIS-Tree algorithm In the steady increase phase, the performance of the modified algorithm is also getting higher and higher. The MIS-Tree algorithm is divided into three phases, each node needs to exchange information, and the flooding tree algorithm only needs the node to broadcast the tree information once, and does not need to reply to the sender for the node receiving the information. any news. Therefore, in the initialization phase of the topology, the flooding tree algorithm consumes less energy than the MIS-Tree algorithm.

However, after forming the network topology, the energy consumption required for topology maintenance caused by node failure is shown in Figure 7. The reason is because the two algorithms are maintained differently. Topology maintenance of the MIS-Tree algorithm, in most cases, localization

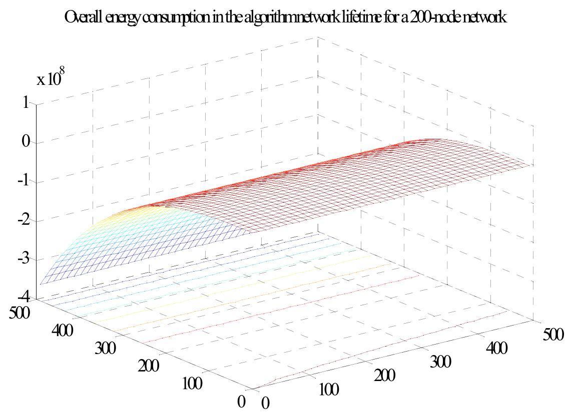

FIGURE 8. Overall energy consumption in the algorithm network lifetime for a 200-node network.

algorithms can be used, which means that the participation in a certain maintenance is usually only a few nodes near the failed node, not all nodes of the entire network. This makes the number of messages sent and received by all nodes in the maintenance phase greatly reduced, so the MIS-Tree algorithm is more efficient in the topology maintenance phase.

Figure 8 shows a network of 200 sensor nodes, running two algorithms in succession, and both experienced topology initialization and multiple network maintenance energy consumption. We prioritize and then average the maintenance energy consumption for each round of each algorithm. It can be clearly seen from the figure that although the initial flooding tree algorithm consumes less energy, after experiencing 13 rounds of maintenance, each node fails and counts as one round. The average energy consumption of the two is roughly equal. MIS-Tree will consume less energy.

In summary, we can see that after considering the energy consumption in the maintenance phase, the global local topology control algorithm has less energy consumption than the pure global algorithm. The global local topology control algorithm has more advantages in energy consumption during the life cycle of the entire network.

V. SIMULATION ALGORITHM AND ANALYSIS

A. IMPROVED TOPOLOGY CONTROL ALGORITHM

In a hierarchical topology-controlled network, the purpose of the cluster head election is to make the energy consumption be distributed fairly on the nodes, avoiding the excessive consumption of energy by some nodes and dying, and prolonging the survival time of the network as much as possible. The rationality of cluster head election, cluster division, intra-cluster and inter-cluster communication is the main content of hierarchical clustering ideas. When you choose to join a cluster, the nodes in the cluster should also consider more factors to make the cluster structure more reasonable. For example, which cluster head node is more suitable for its own leader, which conditions should be available for the best cluster head node.

The energy consumption of cluster reconstruction refers to the number of nodes in the network, the average distance from the node, the size of the data packet sent by the node each

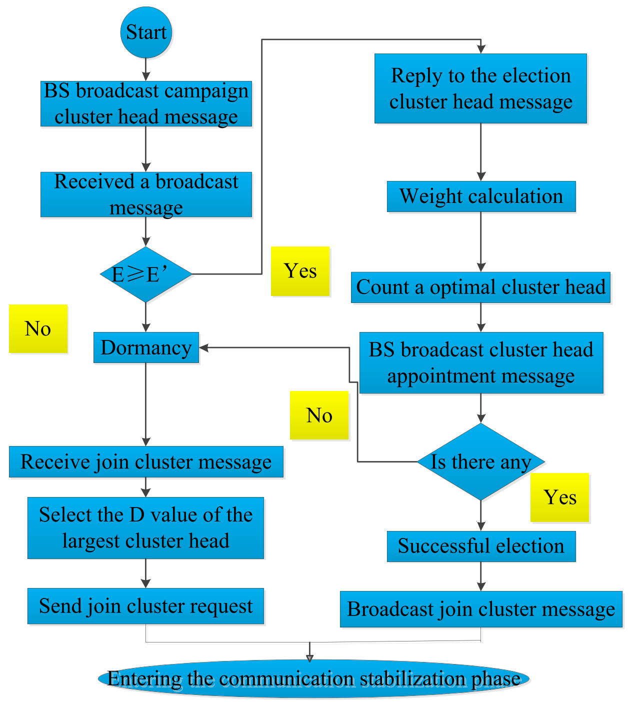

FIGURE 9. CAEC algorithm flow chart.

time, and the consumption of the wireless communication model.

It is assumed that N nodes are randomly arranged in a square monitoring area, and in the process of cluster area division, the monitoring area is divided into a cluster areas of equal area, and the number of nodes in each cluster area is equal. Then there are an average of N/a nodes in each cluster area, including 1 cluster head node and (N/a)-1 intra-cluster nodes.

When the difference between the remaining energy of the cluster head node and the communication energy consumption is greater than a certain value, it continues to receive data from the nodes in the cluster. Otherwise, the cluster head node stops receiving data and announces death, while other nodes in the cluster stop working and wait for the next round to re-define the cluster area. This is repeated until the wireless sensor network is no longer able to complete the monitoring task of the monitoring area.

The improved algorithm CAEC is executed periodically according to the round. Each cycle consists of electing cluster head nodes, dividing cluster regions and stable communication. Figure 9 shows the flow of the algorithm in one cycle.

B. ANALYSIS OF EXPERIMENTAL RESULTS OF LEACH ALGORITHM

The simulation experiment studies the relationship between the cluster head nodes of the LEACH algorithm in the range of 1-10, the number of surviving nodes in the monitoring area, the network energy consumption, and the amount of data received by the BS and time.

When the LEACH algorithm takes three cluster head nodes, the network lifetime is the longest, reaching 860s,

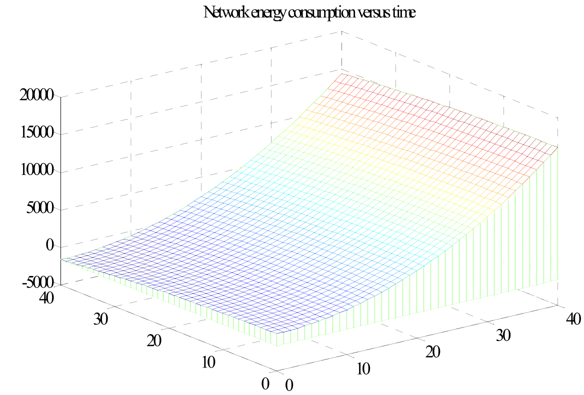

FIGURE 10. Network energy consumption versus time.

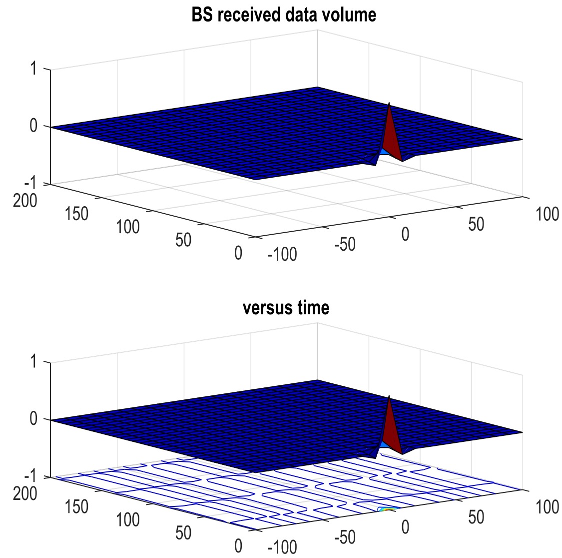

FIGURE 11. BS received data volume versus time.

and the dead nodes begin to appear at 620s. The 10 cluster head nodes have the worst effect, and the death node begins to appear at 50s. When the network is 120s, it is no longer working properly.

The relationship between network energy consumption and time is shown in Figure 10. When only the energy consumption is analyzed regardless of the network lifetime, the four cluster head nodes consume the most energy.

The relationship between the amount of data received by the BS and time is as shown in Figure 11. The amount of data received when the number of cluster head nodes is 1-10 is compared. When the number of cluster head nodes is 3, the data amount is close to 90kbit. When the number of cluster head nodes is 2, 4, and 5, the amount of data is second. In other cases, the amount of data received by the BS is relatively small. The difference in the amount of data received by the BS is mainly due to the different number of cluster head nodes, which results in different clustering structure, which affects the survival time of the network and the efficiency of data collected by the nodes.

The above three simulation results show that the overall performance of the LEACH algorithm is optimal when the

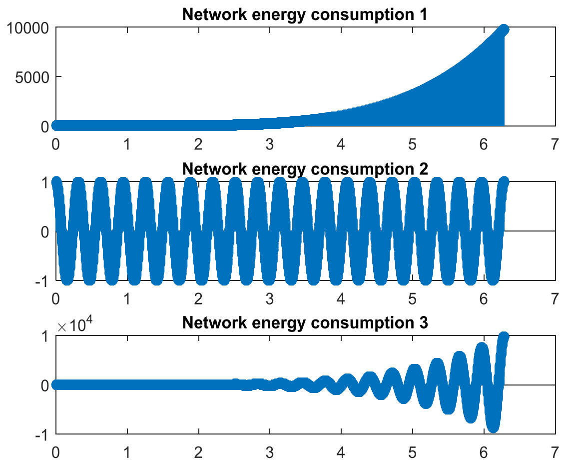

FIGURE 12. Network energy consumption versus time.

optimal number of cluster heads is 3 in the monitoring area of 100 nodes.

C. ANALYSIS OF EXPERIMENTAL RESULTS OF CAEC ALGORITHM

The following simulation experiments study the relationship between the number of surviving nodes in the monitoring area, the network energy consumption, and the amount of received data and time in the cluster head node of the CAEC algorithm in the range of 1-10.

When the CAEC algorithm selects three cluster head nodes in the monitoring area, the network lifetime is the longest, reaching 879s, and the dead nodes begin to appear at 660s. In the case of other cluster heads, the network not only has a dead node earlier, but also the network lifetime is far less than the three cluster head nodes.

The relationship between network energy consumption and time is shown in Figure 12. When the CAEC algorithm in the monitoring area selects 3-10 cluster head nodes respectively, the network consumes more energy. The number of cluster head nodes is 6, 7, 8, 9, and 10 The network energy consumption is about 400J. When the number of cluster head nodes is 3, 4, and 5, the network energy consumption is about 350J.

Figure 13 compares the amount of data received by the BS when the number of cluster head nodes is in the range of 1-10 and the CAEC algorithm is used. When the number of cluster head nodes is 3, the BS receives the largest amount of data, which is close to 120 kbit. When the number of cluster head nodes is 4, the amount of data is second. In other cases, the amount of data received by the BS is relatively small.

The simulation results of the above group show that the overall performance of the CAEC algorithm is optimal when the optimal number of cluster heads is 3 in the monitoring area of 100 nodes.

D. COMPARISON BETWEEN LEACH AND CAEC

The above experimental results show that the network performance of LEACH algorithm and CAEC algorithm is optimal when the number of cluster head nodes is 3. In order to

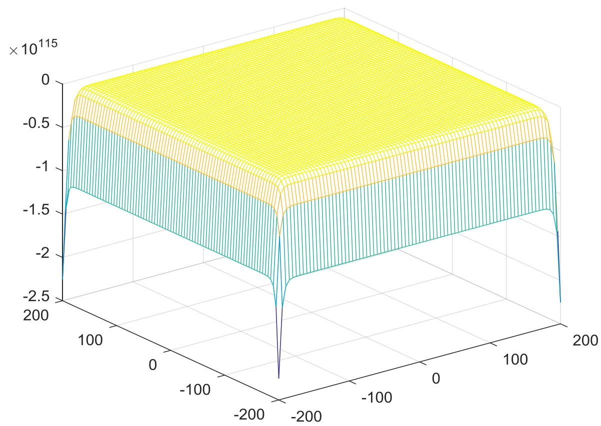

FIGURE 13. BS received data volume versus time.

visually compare the two algorithms, the number of surviving nodes in the monitoring area, the network energy consumption and the received data volume are compared when the number of cluster head nodes is 3.

The LEACH algorithm begins to appear dead at 660s. The CAEC algorithm begins to appear dead at 620s, and the time for the death node is shortened. This is because the CAEC algorithm sends information about the remaining energy and connectivity of the cluster nodes to the cluster head node in each round of election of the cluster head node, which is more energy-consuming than the LEACH algorithm randomly generates the cluster head node in the initial stage of the network. more.

Under the premise of long network lifetime and large amount of data received by the BS, the CAEC algorithm consumes almost the same energy as the LEACH algorithm. The above three experiments show that the improved algorithm CAEC is compared with the LEACH algorithm in the monitoring area of 100 nodes, which prolongs the survival time of the network, that is, the number of surviving nodes in the monitoring area, the network energy consumption and the received data volume. There are different degrees of improvement.

VI. CONCLUSION

The sensor network is an emerging technology, and it is a hot topic of emerging frontier research with high degree of interdisciplinary research. It has broad application prospects. There are still many theoretical and engineering problems to be solved in the process of practical development of wireless sensor networks, so there is a lot of research and development space at all levels and cross-layer design. It is believed that with the deepening of people's research and the continuous resolution of many related problems, wireless sensor networks will eventually enter our lives and play a huge role in social progress. In the field of distributed topology control algorithms, there is still a lot of unknown space waiting for us to go. Explore and discover. It is foreseeable that with the wireless sensor network, from the laboratory to the real life, distribution The topology control algorithm will have more flexible and flexible design requirements, which will be our next research prospect.

The advantages and disadvantages of topology control algorithms are one of the important reasons that affect the performance of wireless sensor networks. In this paper, the existing topology control algorithm is systematically studied and summarized, and an improved algorithm CAEC is proposed. The improved algorithm is implemented by electing the cluster head node, dividing the cluster area and communication stability, so that the cluster head node has the characteristics of high residual energy, close distance BS and large connectivity. The simulation experiment comparing CAEC algorithm with LEACH algorithm affirms the superiority of CAEC algorithm and has the characteristics of prolonging network lifetime.

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